7.0 SYSTEM CONFIGURATIONS

7.1 Introduction

Previous sections of this report have dealt with the economic and operational aspects of the aircraft hazard warning and avoidance problem. Technical data regarding the performance of available sensors under varying conditions of reduced visibility has been developed in the context of the functions to be performed and the level of performance to be provided. It now remains to postulate, from an operational integrated system viewpoint, one or more viable system concepts in which the major system elements, the interface between elements, and the overall functional performance capability are identified.

Systems that have IALM, ROTA and HGA capabilities in general will comprise a primary sensor (or a combination of sensors) which determines the position and presentation of a runway, its centerline and the required touch-down point; and high ground with respect to the aircraft velocity vector, a processor which converts, modifies, or operates upon information derived by the sensor(s) and a display which is fed from the processor. In addition, inputs from other sensors in the aircraft are usually required by the processor in order for it to effectively provide the display with the desired information. The choice of primary system sensor depends in major part upon the maximum range requirements, target signature characteristics and the maximum fog density or precipitation rate that may be encountered. For most system applications the reduced range capability of optical systems, both passive and active, makes them unsuitable.

An IALM system, particularly one which relies upon some measure of runway signature enhancement, can be made compatible with ROTA system requirements. Such a system could also provide HGA capability, although range performance of Ka and V band radars during enroute operations in precipitation-bearing clouds may be marginal. Where a lower frequency band is adopted, adequate HGA performance can be provided except in the most intense storms.

Three system configurations have been postulated ranging in complexity, size and performance as a function of candidate user, i.e., commuter, regional or trunk carrier, the kinds of aircraft operated by the respective carriers and the airfield environment into which they operate.

The assumption is made that most commuter airlines operate regularly into airfields which do not now have Cat II qualified ILS installations and may well not have such a capability for many years. Furthermore, an agressive airline management will continually strive to open up additional service into communities not now provided with scheduled service. Since the aircraft operated by these carriers is restricted in size by regulations,

the proposed IALM and HGA equipment must be restricted in size and probably the complexity as well. The antenna length will probably be 0.5 meter or less. Thus, the first level system is suggested to be one which provides the pilot with the ability to approach and land at any airfield only when the visibility conditions are not worse than 200 ft and 1/2 mile, i.e., Cat I. The economic analysis of Section 3 has already indicated the large benefit in reduced operating losses that could accrue to airline operators from the capability to operate at reduced minima. Table II-17 has shown the distribution of airports in a typical route structure to which this capability could be applied. High ground warning would be provided. ROTA capability would be marginal for a system designed for Cat I operation only. Simple, low-cost runway signature enhancement such as passive corner reflectors is assumed. A design objective should be to take advantage of the existing weather radar bay.

These criteria suggest a system which displays the runway, centerline and threshold and some vertical guidance information.

It is anticipated that regional carriers and some trunks will continue to operate twin and tri-jet equipment into airfields which either are not ILS equipped or if ILS equipped, not Cat II qualified for sometime to come. However, the design objective should be to meet Cat II performance criteria, i.e., 100 ft and 3/16 mile. The IALM system postulated for this category aircraft assumes that antenna size must be restricted to 1 meter or less. The system should perform all of the functions provided for in the previously described system concept and in addition, must provide more precise vertical guidance information.

The trunk carriers generally operate into airfields which are already equipped with ILS, some qualified to Cat II, several more planned for Cat II qualification in the next few years and with a gradual upgrading to Cat III underway for selected airfields. As a consequence, it would appear that the motivation exists for a system which not only provides the High Ground Avoidance capability and approach monitor capability discussed above, but also supplies command information relative to the approach path of sufficient accuracy to determine whether or not the on-board Cat III guidance system is performing properly.

The trunks are gradually requiring aircraft which, in terms of size, cost and potential productivity, will allow for equipment of significantly greater performance and levels of automation. These new aircraft could possibly accomodate antennas of greater length and/or the use of a shared antenna for multiple frequencies, i.e., X band for HGA and weather avoidance and initial orientation during approach and V band or Ka band for the IALM and ROTA tasks. Such a combination would assure the ability to cope with 100 ft visibility fog and/or rainfall rates up to 16 mm/hr while guaranteeing the availability of very high resolution during the last one mile to touchdown, the roll-out phase and finally during taxi.

A fundamental requirement of all three system configurations is that the airfield/runway complex be immediately identifiable by the pilot and that little or no additional workload be imposed on the pilot in the operation of these systems.

In summary then it is seen that at least three candidate system configurations can be identified.

(1) A hazard avoidance radar monitor system providing warning of severe weather (typical weather radar), the proximity of high ground and the location of runway centerline and threshold.

(2) A system which provides all of the features listed in (1) above and in addition, supplies flight director or flight path command information with sufficient accuracy to permit Cat II approach minima to be utilized.

(3) The most complex system will provide all of the features of (1) and (2) above and in addition be of such accuracy that it may be used to monitor an approach under Cat III criteria. Further it shall provide information necessary to roll-out, turn-off and taxi-in conditions of zero visibility.

It should be pointed out that these system configurations have deliberately been chosen to be general in nature. No unique or proprietary features of particular manufacturers' hardware have been included.

7.2 Configuration I - System with Pictorial Situation Display

The system block diagram for the simple radar approach monitor system is shown in Figure II-31.

To produce a situation display, the sensor works as a pitch & roll stabilized ground mapping radar. In the IALM mode, the display would show the runway, together with the track cursor and intercept of the velocity vector. The boresight is pitch stabilized so as to be depressed from the horizontal by the approach path angle. When the aircraft is correctly positioned on the approach path, the boresight intercept and the track cursor should intersect at the touchdown point. Warning of high ground near the flight path is obtained by off-boresight processing of the return radar signals so that any high ground within a predetermined sector produces a warning signal. During enroute flying the display shows a clearance plane display of high ground above a predetermined distance below the flight path. The main characteristics of this system are as follows:

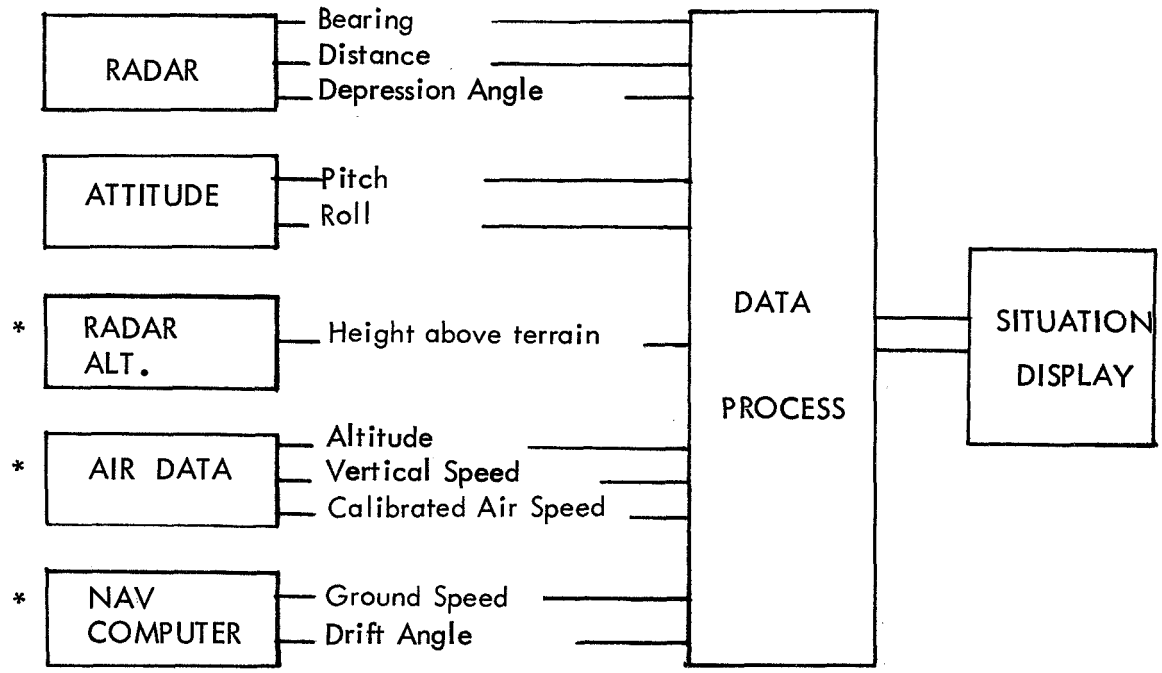


Figure II-31. Candidate System Configuration No. 1

.	Antenna	Monopulse/Interferometer in elevation. Monopulse/Interferometer in azimuth (if X band sensor). Pitch stabilized. Roll stabilized. Azimuth scan.
.	Receiver	Off-boresight processing capability.
..	Input Required	Pitch angle. Drift angle. Ground speed. Selected descent angle. Selected approach path angle.

Note:

* Optional inputs, according to system mechanization

. Outputs - Enroute and During Descent	Warning of high ground near flight path. Profile and plan views of clearance plane display of high ground.
. On approach	Warning of high ground near flight path. Velocity stabilized display of runway with flight vector intercept superimposed. Aircraft track indicated by cursor.
. Taxiway	Situation display showing taxiway.

The approach capability can be achieved without runway enhancement for most domestic operations, however, improved performance could be achieved if runway enhnacement were introduced.

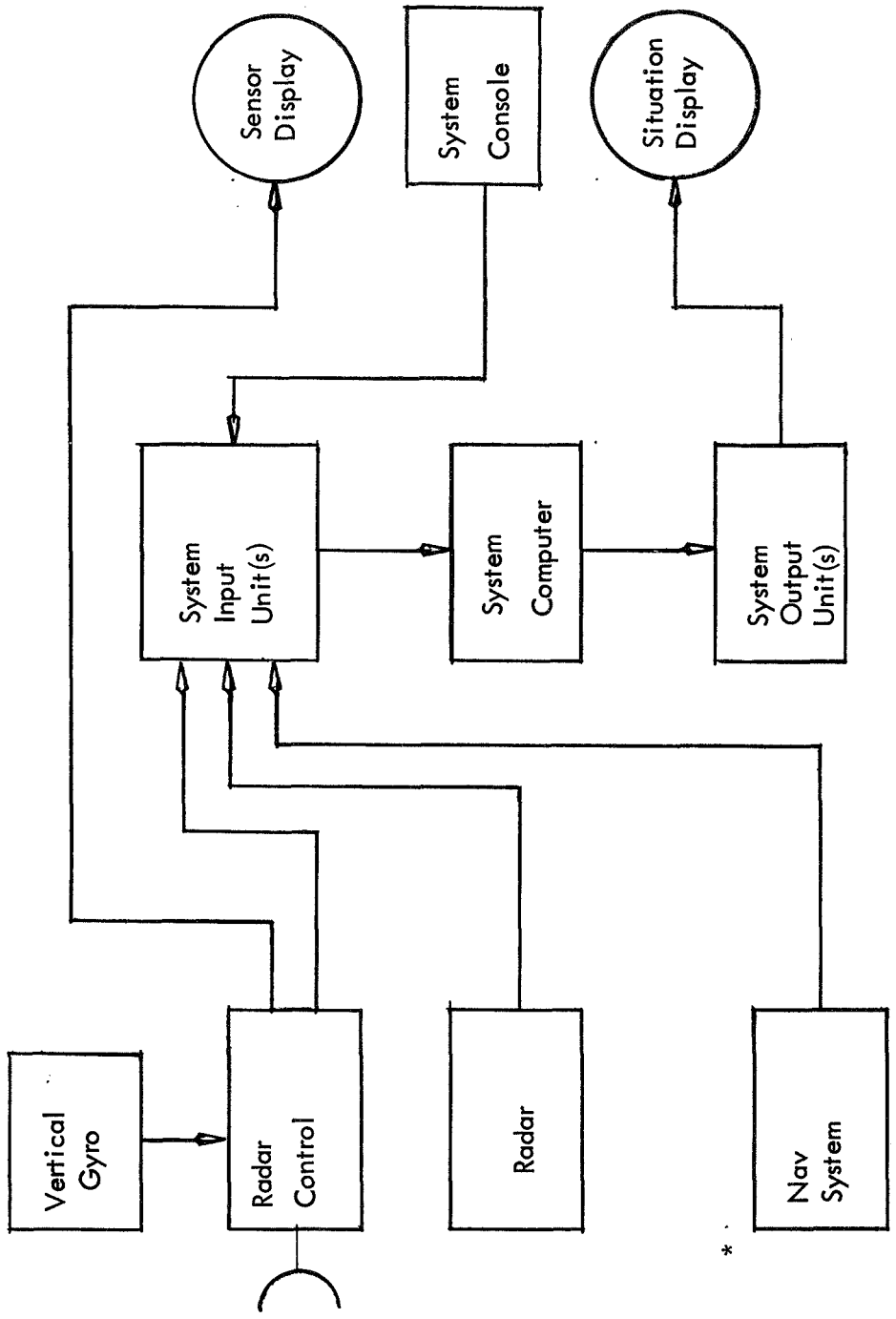
It will be observed that the system requires a minimum of new airborne equipment and radar upgrading, hence, it could be relatively inexpensive.

7.3 Configuration II - System with Director Type Display

The system block diagram for Configuration II is shown in Figure II-32.

For a system with a director type display the radar must determine the aircraft's position relative to a discrete point on the ground. This can only be achieved if the particular point is enhanced by a reflector or beacon so as to produce a readily distinguishable signal. Between 10nm and 5nm from touchdown, the radar in a track-while-scan mode is locked on to the enhanced point, which is defined as being proximate to the touchdown point. The range and angular position of this point relative to the aircraft's axes are obtained by the radar and fed, together with pitch, roll and heading of the aircraft, and runway heading, to a computer which derives the horizontal and vertical distances from the selected glide slope and localizer approach path. The main characteristics of this system are listed below:

. Antenna	Monopulse/Interferometer in elevation. Monopulse/Interferometer in azimuth. Pitch stabilization. Roll stabilization.
. Receiver	Off-boresight processing capability. Track while scan capability.



*Optional input according to system mechanization.

Figure II-32. Candidate System Configuration No. II.

. Computer	Computes distance in two planes from correct approach path.
. Inputs Required	Pitch angle. Roll angle. Drift angle. Aircraft heading. Selected descent angle. Selected runway heading.
. Outputs - Enroute and during descent	Warning of high ground near flight path. Clearance plane display of high ground.
. On approach	Warning of high ground near flight path. Display of runway. Vertical distance from correct approach path. Horizontal distance from correct approach path. Range to touchdown. Predicted touchdown point.
. Taxiway	Display showing enhanced taxiway.

The enroute and descent high ground warning functions are identical to those of Configuration No. 1. The system computer and display are configured to provide aircrew assistance in acquiring the runway on radar.

The radar and system computer requirements are increased in this system over Configuration No. 1.

The advantages of the system (System No. II) are these:

. Pilot manipulation requirements are reduced over Configuration 1.

. Additional interpretation of data display is not necessary.

. Pilot assistance functions can be performed to optimize runway and terrain data acquisition.

The disadvantages are these:

- Increased complexity, hence increased cost.
- Possible decreased overall system reliability, also relatable to increased complexity.

7.4 Configuration III - System with IALM, ROTA, HGA and Weather Radar Capabilities

A maximum capability version of a fully automatic multi-sensor system concept is shown in Figure II-33. The performance capability of this type of system mechanization is as follows:

- Possibility of two additional position sensors.
- A multi-sensor display and processing system.
- Generation of situation and flight director data for approach monitoring.
- Automatic terrain warning and generation of guidance data to assure hazard avoidance.
- Sensor data selection.

The advantages of this approach are:

- Operator manipulation is substantially reduced.
- Cross checking of two independent sources of guidance data can be achieved.
- Flight Director operating techniques can be utilized.
- Missed approach-guidance can be provided.

With runway and taxiway enhancement, an X band sensor can very easily meet the performance requirements of IALM and ROTA. It also provides adequate performance in the HGA mode. As pointed out in Section 6.6 there is no reason why the same X band sensor should not also meet enroute weather radar requirements. In this way, with a single equipment that is not much more expensive than a weather radar, it is possible to provide, in addition to the weather radar capability, IALM, ROTA and HGA capabilities.

It is to be observed that each of the two more complex system approaches can be configured so that the simple radar approach monitor capability of the first system is available in any event. The approach to be used is dependent on relative development and mechanization costs and the overall system objectives.

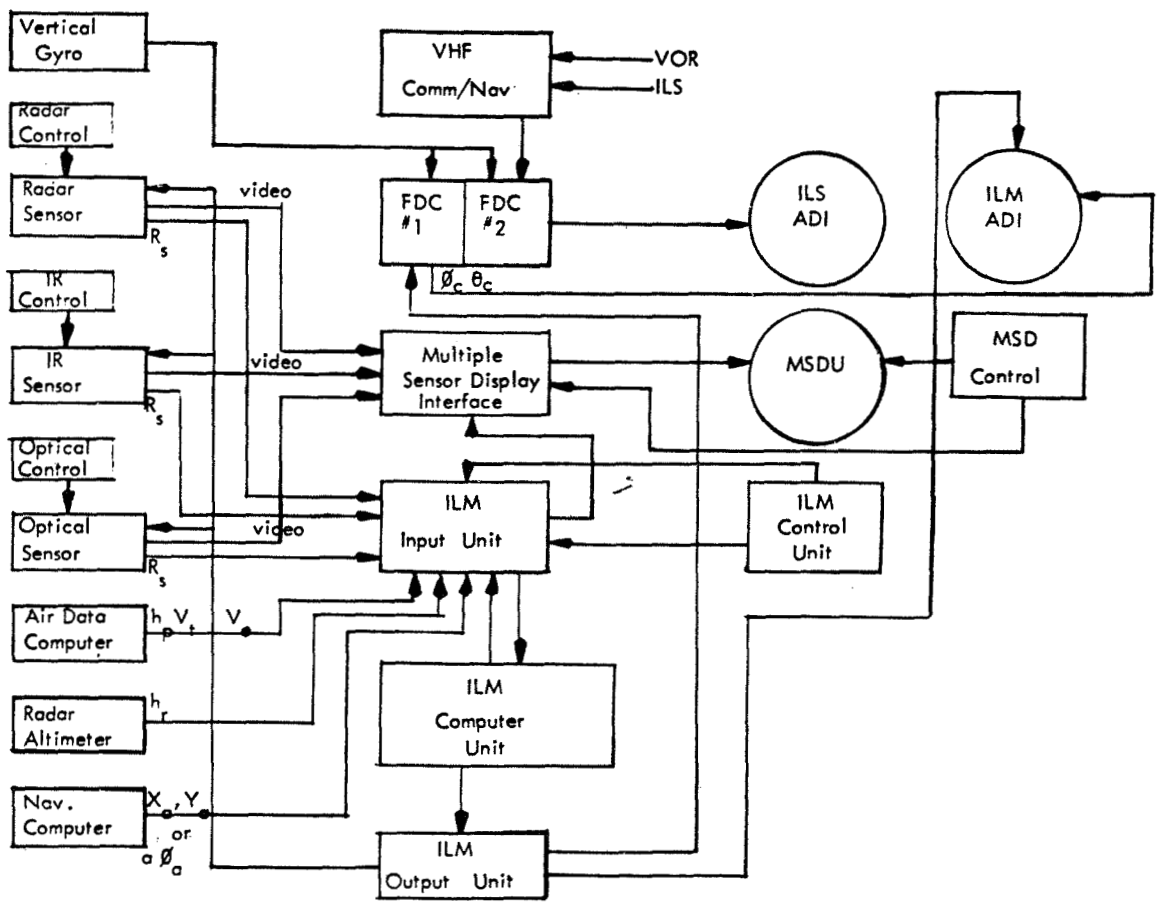


Figure II-33. Candidate System No. 3

8.0 CONCLUSIONS

8.1 Introduction

Each of the preceding sections of this report has dealt with a particular aspect of the hazard warning and avoidance problem. In most cases, each section has had included in it a summary of the major conclusions drawn from the material in that section. It is the purpose of these paragraphs here to draw together all of these related conclusions into one summary section. The conclusions contained herein are factual and summary in nature. Wherever possible reference will be made to the major section of this report which contains the detailed substantiating data which support the stated conclusions.

8.2 Meteorological Effects (Section 2.2)

Optical visibility is most severely restricted by dense fog, which can create situations of essentially zero visibility at ground level. Heavy rain does not necessarily degrade visibility unless accompanied by fog or low clouds. The rainfall rate of 16 mm/hr was taken as the nominal maximum value for this study. Much heavier rains do occur but with small probability of occurrence and short durations. The visibility range in 16 mm/hr rainfall is approximately 5600 feet. A reasonable attenuation of falling snow is somewhat less than that of 4 mm/hr of rain. Smog is similar to fog with a visibility of 2400 feet.

Due to the probability of occurrence of combined rain and fog in the Southern and Southeastern U.S. in the winter months, as one example, it was concluded that the hazard warning and avoidance system must have adequate runway detection performance and high ground avoidance performance under the condition that both fog and heavy (16 mm/hr) rainfall exist simultaneously.

8.3 Accident Statistics (Section 2.3)

Of the 820 accidents which occurred to certificated air carriers during the period of 1958 to 1967, 110 could be classified as those in which the existence of an airborne hazard warning and avoidance system could have significantly contributed to the avoidance of these accidents. These 110 accidents accounted for 37% of all of the fatalities suffered in the 820 accidents. 63% of these "applicable" accidents occurred during the final approach (24% - 10 miles to 1 1/2 miles from runway threshold) and landing (39% - 1 1/2 miles to runway threshold) phases of the flight. The final approach accidents typically

occurred in poor visibility. 25 of the 43 landing phase accidents occurred in "daytime" conditions, implying that the pilot could see the runway.

There is a need for either high-ground or runway orientation at distances up to 10 miles from runway threshold. Few accidents occur beyond 10 miles. It appears that visual acquisition of the runway is, of itself, not adequate for safe operation. A combination of instantly recognizable runway identification and orientation coupled with command guidance information similar to ILS but generated completely independently of ILS is required for proper landing operations.

8.4 Economic Benefits (Section 3 and Appendix A)

Poor visibility has an adverse economic effect on flight operations by creating delays in landing or a diversion to an alternate airport because of an inability to land. This economic impact is separate and above from the safety aspect of the problem. The inclusion of equipment to provide added landing capability (ability to operate at lower minimums) presents a potential way to avoid some of the penalties. The actual cost benefit achieved by such capability varies as the airline route structure, particular airport weather frequency statistics, and traffic density.

For the typical trunk, regional, and commuter airline route structures hypothesized for this study, annual per aircraft savings of as much as $25,000 for the trunk carrier, $53,000 for the regional carrier, and $45,000 for the commuter airline were computed, for a particular airport/weather situation assuming operation down to Category III, but only taking benefit for performance in weather below 1/2 mile visibility. Additional total savings could also be achieved for those situations where the minima are above 1/2 mile. The majority of the savings is felt in achieving operation down to 1/16 mile visibility, but a significant cost impact can be identified in getting from 1/2 mile to 3/16 mile conditions. Again, for the three carrier levels studied, annual per aircraft savings of $13,000 for the trunk, $27,000 for the regional, and $21,000 for the commuter carrier were postulated in lowering the operating minima from 1/2 to 3/16 mile. While many other combinations of route structures, weather statistics, and operating frequency can be studied, the foregoing figures identify the order of magnitude of equipment cost that could be considered on a cost benefit basis. One major conclusion of this particular analysis was the obvious cost effectiveness of a hazard warning and avoidance system just in reducing the operating minima at non-ILS runways.

8.5 Desired Characteristics (Section 4)

The hazard warning and avoidance system should provide capabilities for High Ground Avoidance (HGA), Independent Approach and Landing Monitor (IALM), and Roll Out and Taxi Aid (ROTA) functions. These system functions are predicated upon a series of safety and economic justifications. In the IALM mode it is desired that the system generate command information or error signals relative to a specified synthetic glide slope and localizer that are comparable in type and accuracy to that of a properly functioning ILS. Pilot workload and display interpretation requirements should be minimized; particularly during final approach conditions.

The primary characteristics of required system performance include:

Maximum Range	
HGA Mode	5-10 n. miles
IALM Mode	7-10 n. miles
Azimuth Coverage	$\pm 30^\circ$
Azimuth Error	0.8°
Elevation Coverage	$+ 5^\circ$ $- 15^\circ$
Elevation Error	0.4°
Offset Error at Threshold	$\pm$ 40'
Scan Rate	
Azimuth	2.3 cycles per sec.
Elevation	1.5 cycles per sec.
Glide Slope Angle	$2\text{-}10^\circ$
Cross Wind Component	22-28 knots (10° crab)

8.6 Current Approach and Landing Aids (Section 5)

Theoretically ILS can be developed to sufficient accuracy in the localizer and glide slope planes to be used for Category III landings. Unfortunately, it is still subject to local distortion, bends, etc. Quantitative range to touchdown information is not

available to the pilot from existing ILS. Advanced scanning beam ILS concepts are under development, but their authorization and/or implementation have not yet been established. Neither of these ILS-type systems however will provide the back-up capability desired for an IALM, where independence from the ILS system is a design criteria.

VOR/DME is not currently authorized for use in Category I conditions. Such developments as Precision VOR when used with specialized airborne equipment, are capable of the accuracies required for Category I (and perhaps Category II) landings. Ground Controlled Approach (GCA) presently is not authorized for civilian use below Category I although it has been demonstrated within the military to be capable of Category II landings. Although accuracy improvements are possible, the inherent high costs of equipment and 24 hour GCA teams preclude the utilization of GCA for Category III.

8.7 Sensor Performance (Section 6)

Sensor performance was studied primarily with regard to the requirements related to runway detection in the ILM mode and high ground detection in the HGA mode. The study of radar sensors led to the summary recommendation of two major possible radar systems. The brief review of optical sensors which was performed did not identify any promising alternatives in either the visible spectrum or the infra-red spectrum.

Runway identification by radar means requires that the runway be enhanced by reflectors or beacons. Ka band provides the best capability for unenhanced runways but its limited clear weather range capability, 3 to 5 n.m., is seriously reduced by heavy rain. X band and Ku band provide the required 7-10 n.m. range capability when runway enhancement is used. X band is limited only in that it does not possess the resolution required to produce a radar map of the runway. The higher frequency bands, both Ka and V bands, have limited range capability when reflectors are used and they require excessive power levels in beacons, so neither is recommended.

For the detection of high ground, both X band and Ku band provide adequate performance. The range at Ka band is marginal and the range at V band is poor.

The roll out and taxi requirements for Category III operations tend to favor the higher frequency bands, Ka and V bands, because of their superior resolution properties.

In summary, two configurations are recommended for further pursuit. The first of these is a combined ILM and HGA radar system. The system uses

- Ku band frequency
- 1 m antenna aperture in azimuth
- runways enhanced by reflectors
- 1.0 and 0.1 μs pulse widths.

The second is a combined ILM, HGA, Weather and taxiway guidance radar system. This single composite system includes the features of

- X band frequency
- 1 m antenna aperture in azimuth
- runways enhanced by reflectors or beacons
- 5.0 and 0.1 μs pulse widths.

The former system offers slightly better performance when a separate weather radar is available. The latter system offers the possibility of combining the very important ILM and HGA functions with the existing concepts and hardware developed for weather radar applications.

8.8 System Configurations (Section 7)

Based on the sensor performance analysis of Section 6, there are several general system configurations available with the overall required system performance. Due to the various requirements of potential users of hazard warning and avoidance systems, several approaches were investigated. Without runway enhancement, high ground avoidance and some measure of approach monitoring capability can be provided. With some form of runway enhancement, the problem of runway detection and identification is minimized or eliminated. Using monopulse or interferometer techniques for elevation scanning, quantitative command guidance information can be generated and displayed relative to a synthetic glide slope. These systems can provide either monitoring information or actual guidance information, according to the concept of system application. Using concepts of display such as the Electronic Attitude Director Indicator, it is possible to generate either a synthetic runway perspective, or an actual radar or TV view of the runway attitude information, command signals relative to a theoretical glide slope, and a predicted touchdown point relative to the displayed runway.

With runway and taxiway enhancement, either an X band or Ku band sensor can very easily meet the performance requirements of IALM and ROTA. It also provides adequate performance in the HGA mode. As pointed out in Section 6, it is possible to utilize the same X band sensor for these functions that meets enroute weather radar requirements. In this way, with a single equipment that is conceivably not much more expensive than a weather radar, it is possible to provide in addition to the weather radar capability, IALM, ROTA, and HGA capabilities.

9.0 RECOMMENDATIONS FOR FUTURE DEVELOPMENT

9.1 Introduction

Provisions of the original Statement of Work for this study effort called for the development of a comprehensive program aimed at the acquisition and flight test of a demonstration hazard warning and avoidance system. During the conduct of this study, as the operational analysis and technology investigations were performed, marked information gaps in certain basic areas of interest began to appear. Therefore, as the overall development plan is discussed in this section, major emphasis has been placed on closing these information gaps as the necessary next step in an integrated plan.

Definitely this current study, as documented in this volume, has provided the depth of substantiating data necessary as a prerequisite for a decision to continue the development of the hazard warning and avoidance system. The problem has been identified and quantified in three areas - operational, economics and flight safety. Although all of these areas interrelate and interact, it has been shown that each of them would substantially benefit from the functions and capabilities afforded by the system concepts postulated in this study and in a manner that would responsibly benefit both the airline operators and the traveling public. In parallel, an extensive study into the technology of existing sensors has shown that, in general, performance of the required level as defined by the operational problem analysis, is currently available within today's state of the art. However, the sensor technology performance analysis has been based, in part, on an extrapolation into an area of uncertainty related to target signatures and low grazing angles which must be resolved as the logical next element of the development program. Similarly, the subject of flight deck information display content and format both affects and is affected by the entire system concept to such a degree that additional emphasis must be placed on this investigation concurrently with the sensor analysis.

9.2 Immediate Recommendations

"Recommended Development Program" (p.176) describes the overall plan recommended for the development and flight demonstration of a hazard warning and avoidance system. As a device to spotlight the relative importance of the two immediate areas of concern, namely, sensor performance and display concept, these two tasks will be discussed separately, and indeed, are identified as comprising a separate and distinct phase of the development cycle.

9.2.1 Sensor Static Feasibility Tests (Ground Based). - The sensor performance of an airborne or self-contained IALM depends primarily upon the characteristics of the signals scattered back from the ground at grazing angles in the range of 1° to 10°. Data appearing in Section 2 of Volume III of this report show that very few quantitative measurements have been made of the scattering coefficient of various terrains at grazing angles of less than 10°.

Existing curves for X and Ku band frequencies can probably be extrapolated down to approximately 3° with reasonably accurate results. However, extrapolation at Ka band could give misleading data, while no base data of any significance at all exists for V band. Verification of the validity of extrapolation, or the establishment of a new set of empirical data at angles down to 1° for various frequencies is mandatory prior to a final selection of equipments suitable for flight test. Investigation of the effects of different techniques of polarization (vertical, horizontal, or circular) should also be conducted as they pertain to various frequencies.

The ability of a mapping radar to detect and display an airport runway depends upon the difference between the scattering coefficient of the runway and that of the adjacent ground. At a 10° grazing angle the scattering coefficient of grass is about 20dB above that of concrete and 10dB above that of asphalt. Due to the lack of test data, the performance of the frequency bands considered at angles down to 1° has not been verified. At Ka and V bands, for instance, the surface roughness of runways is becoming large as compared with the wavelength, which may invalidate a straight extrapolation of existing data. The problem of diminished contrast for an unenhanced runway in proximity to a paved intermediate area rather than grass, or a snow-covered runway, poses a series of unanswered questions concerning target signatures. In the case of runway enhancement techniques, the signature characteristics of various reflector/beacon devices also needs empirical verification. For this reason, a comprehensive series of experiments should be run using available equipments at the frequencies of interest and ground-based towers under the requisite conditions of grazing angle and target conditions, in order to establish a data base to be used for the final selection of frequency and runway enhancement to consider for ultimate flight test.

The following paragraphs describe the initial work necessary for the desired sensor performance tests:

Radar, IR, and Visual Spectrum sensor data generated during the Phase I feasibility study should be used to select candidate sensors for static and flight tests. Sensor test plans should be evolved and sensors will then be procured and static testing will be initiated.

These tests should be designed to provide data relating to the following aspects:

- Radar cross sections of various surfaces (asphalt, concrete, grass) as a function of frequency, polarization and grazing angle of very shallow grazing angles (as low as 1 degree). Included in this evaluation will be consideration of runway contrast such as snow cover, paved areas, etc.

  The effect of circular polarization on rain clutter cancellation at shallow grazing angles.

  The optimum polarization technique(s) for a landing monitor system.

The effect on signal return, background levels and attenuation of both visual and IR systems at shallow depression angles.

The effect of utilizing frequency agility techniques as a device for increasing runway contrast.

The relative performance improvement in both radar and IR spectrums of various target enhancement techniques.

The ability of both visual (electro-optical) and IR sensors to perform the Roll-out and Taxi Aid functions for Category IIIC operations.

In addition to obtaining basic sensor data, it will be necessary to assess the practicability of pilot display interpretation for purposes of runway identification. The ratio of runway width to radar beam width which allows identification of the runway (due to the absence of back scatter) should be determined.

9.2.2 Display System Simulation and Evaluation. - In great measure the utility and acceptance of any hazard warning and avoidance system, in particular one whose primary function is one of an Independent Approach and Landing Monitor, is dependent upon the proper processing and display of necessary situation and command information. A whole spectrum of issues and controversies always arises when the subject of cockpit displays is introduced. Some of these issues concern such areas as head-up vs. head-down, real world vs. symbolic presentation, moving PPI vs. touchdown tracking, situation vs. command information, etc. All of these issues must be investigated in a realistic and scientific manner prior to the establishment of a recommended flight test configuration.

The following paragraphs describe the initial work necessary for preliminary display system evaluation.

1. Define and model theoretically the dynamics of the landing phase for representative current and advanced commercial transports including such considerations as safe go-around which are dependent on handling characteristics, size and approach speed. Determine which equipments, computer programs, schedules and costs would be required and perform preliminary design of a simulation facility for the landing phase situation. Consider, wherever possible, the utilization of existing available simulation facilities. Incorporate flexibility to accommodate the full complement of sensor systems which have application as elements of an independent landing monitor. Survey existing displays and make recommendations for incorporating that computer/display system interface which most closely approximates the IALM system needs.

2. Determine from such existing information as EADI flight tests, Ames flight tests and others, the capability of the pilot to land, roll-out, and taxi aircraft using television cameras and cathode-ray tube displays. Devise an evaluation technique to determine relative pilot performance as a function of deterioration in display information resolution and content. Ascertain minimum information requirements for this type of display and establish sensor and processing specifications to provide these minimum requirements.

3. Based on the results of Item 2 above, one or more candidate display systems could be procured for the purposes of system simulation and evaluation. In particular, the following aspects will be considered:

- Display Symbology. This will include assessment of the ease of interpretation of the director and situation data.

  Display Response.

  Accuracy of the display itself and the accuracy with which command flight path can be achieved.

  Control motion in response to display command.

- Adequacy of display of aircraft vertical situation data.

In addition to an operational and functional assessment, a detailed assessment of the ease of interfacing and the degree of difficulty of changing symbology could be achieved. The operational and technical assessment would not be exhaustive but would allow final selection of the flight test display system(s).

9.3 Recommended Development Program

From the standpoint of an overview of all of the elements in an integrated development program, the recommended tasks have been identified and grouped in the following manner. The tasks gathered under Feasibility Tests have already been described in Section 9, p.173 of this report.

A brief outline of additional interrelated tasks is included herein.

9.3.1 Program Outline. -

Program Definition

Feasibility Tests - These tasks are considered necessary for immediate implementation in order to establish the primary system concept for future development efforts.

Sensor Static Feasibility Tests
Display System Simulation and Evaluation

System Definition - Once the basic system concept and sensor feasibility has been established, a detailed system configuration must be defined in order to scope the actual development program from a cost and schedule viewpoint.

Detailed Technology Analysis
Flight Test System Configuration Definition
Detailed Flight Test Planning
System Specification

Program Scope and Cost - These tasks should provide detailed and accurate estimates of the costs and schedules associated with an actual hardware system acquisition and test program.

Vendor Proposal Evaluation
Cost and Schedule Preparation

System Acquisition - The following tasks represent the necessary sequential elements contained in the creation of a hazard warning and avoidance system suitable for flight test evaluation.

Flight Test Instrumentation Design and Procurement
Test Aircraft Procurement and Modification
Hardware Procurement and Detail Design
Fabrication Assembly and Bench Check-Out of Hardware
Installation and Check-Out in Test Aircraft
Flight Proving of the System

System Evaluation - The system once built and checked out, should be subjected to extensive and carefully planned flight test evaluation under a varied and representative set of operational conditions.

Flight Test Evaluation of Alternative Configurations
Flight Test Data Reduction and Analysis

Figure II-34, Program Flow Diagram, illustrates an overall view of the logical relationship between all of the previously identified tasks.

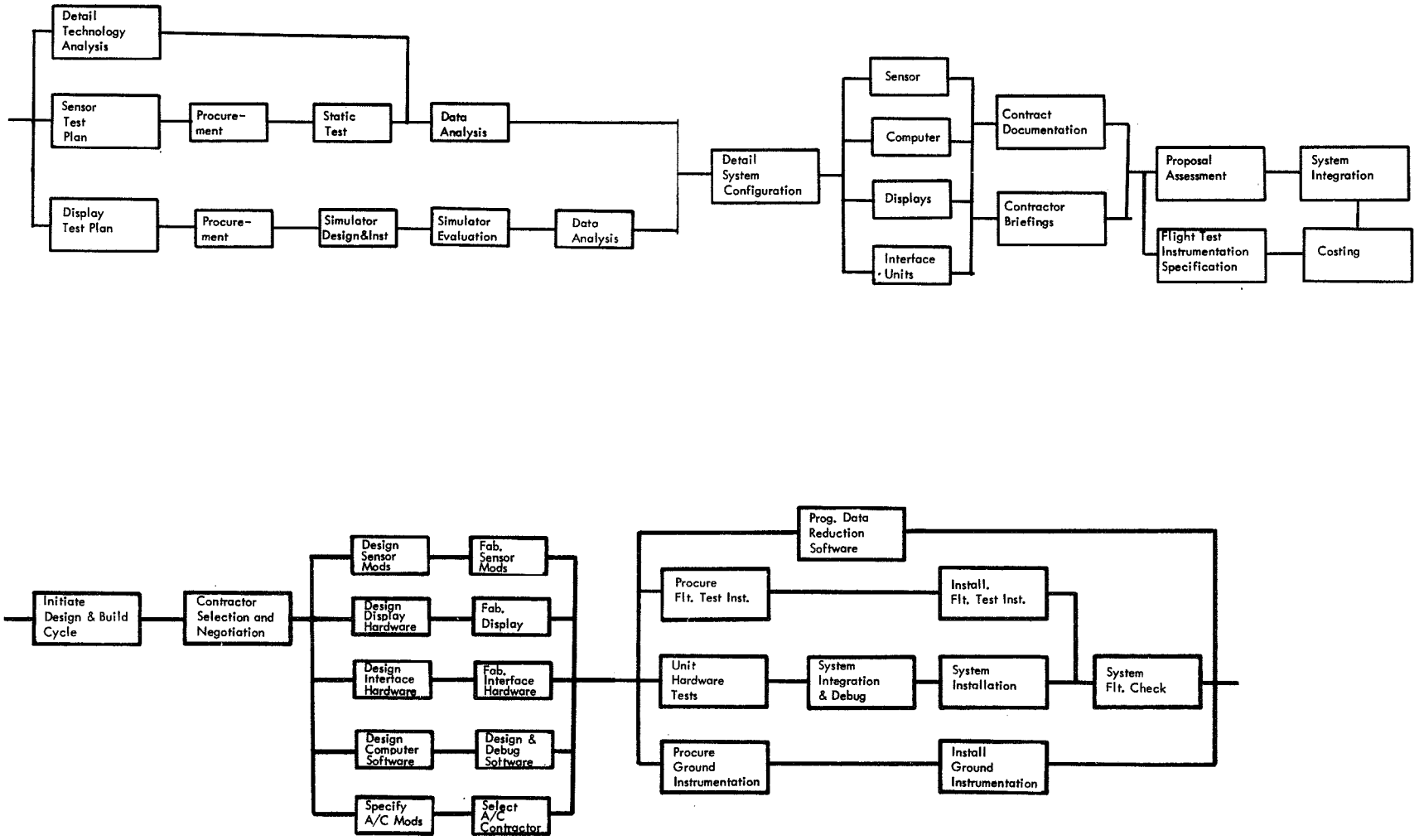


Figure II-34. Program Flow Diagram

REFERENCES

1. Eldridge, R. G., "Haze and Fog Aerosol Distributions." Journal Atmos. Sciences, Vol. 23, Sept. 1966.

2. Barhydt, H., "The Application of Infrared Technology for Aircraft Landing Aids", Hughes Aircraft Co., Culver City, California, 1969.

3. Chu, T.S. and Hogg, D.C., "Effects of Precipitation on Propagation at 0.63, 3.5 and 10.6 Microns, BSTJ May - June 1968.

4. Wilson, J.W., "Use of Radar in Short Period Terminal Weather Forecasting". 13th Con. Radar Meteorol.

5. Handbook of Geophysics and Space Environments, Air Force Cambridge Research Laboratories; McGraw Hill Book Co.

6. Hogg, D.C., "Millimeter Wave Communication through the Atmosphere", Science Vol. 159, No. 3810, pp. 39-46, Jan. 1968.

7. Warner, C. and Gunn, K.L.S., "Measurement of Snowfall by Optical Attenuation", Journal App. Meteorol, Vol. 8, pp. 110-121, Feb. 1969.

8. Gunn, K.L.S. and East, T.W.R., "The Microwave Properties of Precipitation Particles", Quart. Journal Royal Meteorol. Society, Vol. 80, pp. 522-545, Oct. 1954.

9. Wisler, C.O. and Brater, E. F., "Hydrology", 1955

10. Collis, R.T.H., "Laser Radar Applications, Microwaves", March 1969.

11. Flight Safety Foundation, "Aircraft Accident Statistical Analysis and Distribution Study", Report prepared for PNSI, May 1969.

12. PNSI, "Progress Report, Aircraft Hazard Avoidance System", NASA Contract #NAS 12-2108, 23 May 1969.

13. Climatological Summaries, Final Report, Contract FA-67-WAI-129, US Dept. of Commerce, ESSA, Environmental Data Service, National Weather Records Center, Ashville, N.C., June 1969.

14. "Alternative Approaches for Reducing Delays in Terminal Areas," Project No. 177-611-OIR, Dept. of Transportation, FAA Systems Research & Development Service, Washington, D.C., 20590, Nov. 1967.

15. "FAA Statistical Handbook of Aviation," Dept. of Transportation, FAA, 1968 Edition.

16. RTCA Special Committee 117, Paper 24-69/SC 117-48, Jan. 31, 1969.

17. RTCA Special Committee 117, Paper 19-69/SC117-46, Jan. 27, 1969.

18. NASA CR1188 -"Analysis of Cumulative Errors Associated with Cat II and Cat III Operations with Requirements for Additional Research."

19. ICAO, Annex 10, October 1965. Vols. I and II, "International Standards and Recommended Practices , Aeronautical Telecommunications".

20. Kayton, M. and Fried, W.R., "Avionics Navigation Systems," Pg 539-40, Wiley & Sons, 1969.

21. Litchford, G.B., "Low Visibility Landing", Astronautics & Aeronautics, Nov. 1968 and Dec. 1968.

22. Lepers, J., Turcat, A. and deBayser, P., "The Current State of the SUD-LEAR Programme to Reduce Landing Minima and Develop an All Weather Landing System," Library Translation No. 1215, Royal Aircraft Establishment, Feb. 1967.

23. Marino, D.J. and Ward, A.E., "A Survey of Instrument Landing Systems", Working Paper-2332, MITRE Corp., Bedford, Mass., Aug. 1968.

24. Rhodes, D.R., "Introduction to Monopulse", McGraw-Hill Book Co., Inc. New York, 1959.

25. Skolink, M.I., "Introduction to Radar Systems", McGraw-Hill Book Co., Inc. New York, 1959, pp. 181 and 574.

26. Cosgriff, R.L., Peaks, W.H. and Taylor, R.C., "Electromagnetic Properties of Natural Surfaces with Applications to Design of Radars and Other Sensors". (Terrain Handbook) The Ohio State University Research Foundation, Feb. 1959.

27. Panasiewicz, J.J., "Enhancement of Aircraft Radar Return by the Use of Airborne Reflectors and Circular Polarization", IRE Conv. Record, Vol. 4, Pt. 8, pp. 89-96, 1956.

28. Medhurst, R.G., "Rainfall Attenuation of Centimeter Waves", Comparison of Theory and Measurement", IEE Trans. on Antennas and Propagation, Vol. AP 13, pp. 550-563. July, 1965.

29. Ryde, J.W. and Ryde, D., "Attenuation of Centimeter and Millimeter Waves by Rain, Hail, Fogs and Clouds", British General Electric Company Report No. 8670, May, 1945.

30. Dickson, D.R. and Hales, J.V., "Computation of Visual Range in Fog and Low Clouds", Journal of App. Meteorology, Vol. 2, No. 2, April, 1963.

31. Matveev, L.T., "Physics of the Atmosphere", Israel Program for Scientific Translation, Jerusalem, 1967.

32. Kirkpatrick, G.M., "The Use of a Monopulse Radar as a Low Approach Aid", IEE Translation, Aerospace Electronics Systems, Vol. AES-2 No. 3, pp. 353-A, May, 1966.

33. Latmiral, C. and Sposito, A., "Radar Corner Reflectors for Linear and Circular Polarization," J. Res. Nat. Bur. Standards, Vol. 66D, No. 1, pp. 23-29, Jan. - Feb., 1962.

34. Microwave Journal, Microwave Engineers Technical and Buyers Guide Edition, Feb. 1969.

35. Starling, R.I., "Ground Clearance Monitoring by Radar", 19th Annual Air Safety Seminar, Nov., 1966.

36. "Microwaves", p. 26, April, 1969.

37. Blanchard, D.W., "Decision Height and RVR Minima," Journal Institute of Navigation (London), Vol. 21, No. 2, April 1968.